Naval Surface Warfare Center
Carderock Division
West Bethesda, MD 20817-5700

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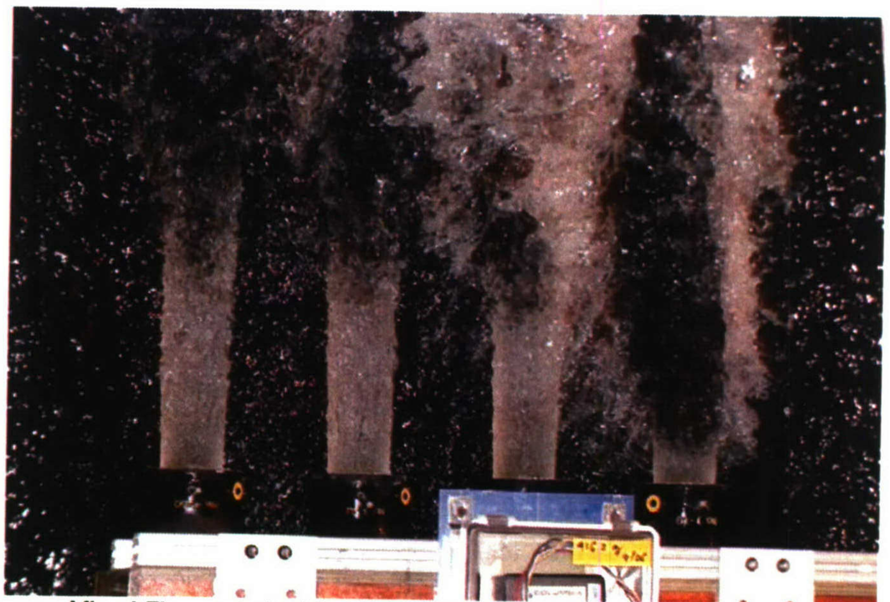
Hydromechanics Department Report

Mixed-Flow Waterjet (MxWJ) Model 5662-1: Initial Study of Yaw Effects on Waterjet Powering and Transom Depth Effects on Waterjet Priming

By
Dominic S. Cusanelli



Mixed-Flow waterjet Model 5662-1 powering run at 3 degrees Yaw

NSWCCD-50-TR–2007/093 Mixed-Flow Waterjet (MxWJ) Model 5662-1: Initial Study of Yaw Effects on Waterjet Powering and Transom Depth Effects on Waterjet Priming

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14. ABSTRACT
This report is a partial documentation a series of model-scale experiments conducted 5/07-6/07, on Mixed-Flow Waterjet (MxWJ) Model 5662-1, a waterjet propelled variant of the Joint High Speed Sealift (JHSS) hull platform. This document contains data and evaluations from initial investigations into the following two waterjet topic areas:
(1) The effects of model yaw angles on waterjet powering. Model-scale rotor force measurements of thrust and torque at angles of yaw up to 3 degrees showed little variation compared to the equivalent forces measured at zero yaw angle. Model drag and side forces, as expected, showed substantial increases as yaw angle was increased.
(2) The effects of variations in model transom depth, and by extension the submergence of the waterjet pump inlet, on the priming of the waterjets. Visual observations as to the state of fluid flow through the waterjets indicated that the initial waterjet design criterion of retaining 50% of the rotor submerged was conservative, and could be relaxed somewhat for future designs.

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FIGURES

ABSTRACT

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(1) The effects of model yaw angles on waterjet powering. Model-scale rotor force measurements of thrust and torque at angles of yaw up to 3 degrees showed little variation compared to the equivalent forces measured at zero yaw angle.

(2) The effects of variations in the submergence of the waterjet pump inlet on the priming of the waterjets. Visual observations as to the state of fluid flow through the waterjets indicated that the initial waterjet design criterion of retaining 50% of the rotor submerged was conservative, and could be relaxed somewhat for future designs.

ADMINISTRATIVE INFORMATION

Funding for the evaluation of the Mixed-Flow Waterjet was through the US Navy's Sealift R&D Program, managed through the Strategic & Theater Sealift Program Office PMS 385. The Joint High Speed Sealift (JHSS) Program Project Manager is William Davison (PMS 385). The JHSS Hydro Working Group (HWG), which includes representatives from NAVSEA, NSWCCD, ONR and CSC, coordinates all hydrodynamic, propulsion, hullform, and structural loads R&D for these combined programs.

Model tests were conducted at the David Taylor Model Basin, Naval Surface Warfare Center, Carderock Division Headquarters, (NSWCCD), by the Resistance & Powering Division (Code 5200), under work unit numbers 07-1-2125-145/146.

INTRODUCTION

The Joint High Speed Sealift (JHSS) was a potential FY12 ship acquisition sponsored by OPNAV N42. The program was originally designated the Rapid Strategic Lift Ship (RSLS) as outlined in "Rapid Strategic Lift Ship Feasibility Study Report" [Ref. 1]. In the "Joint High Speed Sealift (JHSS)" presentation [Ref. 2], the ship's capability was broadly described as being able to "Embark design payload, transport it 8,000 nm at 36 knots or more, and disembark it to a seabase or shore facility". Waterjets are one of three different types of propulsion systems to be evaluated on the JHSS parent hull platform.

The entire evaluation of waterjet propulsion on the JHSS hull platform is to include the construction and testing of two model hulls, the Axial Waterjet (AxWJ) Model 5662, and the Mixed-Flow Waterjet (MxWJ) Model 5662-1. The extensive testing planned for the two waterjet models, which will extend over a period of more than eight months, will be summarized in a single volume after the conclusion of the test programs and analysis period. In the interim, reports of smaller scope, documenting the numerous series of experiments, will be prepared.

This document contains data and evaluations from a selection of model-scale experiments, presented in the Test Agenda, Appendix A, Table A1, conducted on the Mixed-Flow Waterjet (MxWJ) Model 5662-1, in the waterjet topic areas of (1) the effects of model yaw angles on waterjet powering, and (2) the effects of variations in the submergence of the waterjet pump inlet on the priming of the waterjets.

BACKGROUND AND PURPOSE

The propulsion performance of a ship propelled by open propellers suffers when the ship enters into a turn. Performance degradation is due to factors such as the modified angle of flow into the propellers induced by the ship's non-zero yaw and pitch angles, unsteadiness and asymmetry of the wake into the propellers, propeller and strut cavitation, etc. However, experiences of open propeller performances in turns are not easily transferred to waterjet-propelled hulls. Limited knowledge exists as to the effects of yaw angle on waterjet performance. Due to the location of the rotors inside the waterjet, where the inflow will retain a greater degree of uniformity even in a turn, it is surmised that measured rotor forces will be only minimally affected by reasonable (1-3 degree) angles of yaw. The current model assessment will evaluate this hypothesis.

In the application of waterjets to the JHSS hull platform, four high-powered, large-diameter waterjets were required to be housed in the transom. The transom was designed to a relative minimum total volume required to house the four waterjets and associated hardware, while adhering to some basic arrangement and sizing criteria as prescribed by the HWG, as outlined by Cusanelli and Carpenter [Ref 3]. Transom depth was dictated primarily by the criterion, that, in order to assure rotor priming, half of the rotor diameter, as measured at the waterjet inlet, should remain submerged at design displacement. This criterion resulted in a transom design with a substantially greater draft and volume that that of the JHSS baseline hull with 4-screw propulsion. Increased transom size places the waterjet variant at a distinct disadvantage in terms of hull resistance when compared to the parent hullform. A relaxation of this waterjet submergence criterion would likely reduce the hull resistance of the waterjet variant. The current investigation will determine the feasibility of reducing the waterjet inlet submergence while retaining the ability for the waterjets to be self-priming.

HULL MODEL

Mixed-Flow Waterjet (MxWJ) Model 5662-1, Figure 1, represents one of two candidate waterjet-propelled variants of the JHSS hull platform. Model 5662-1 was built of fiberglass to a linear scale ratio $\lambda = 34.121$, and LBP = 27.86 ft (8.5 m), and manufactured at NSWCCD. The MXWJ model scale ratio is equivalent to that of the JHSS Baseline Shaft & Strut (BSS) hullform Model 5653 [Ref. 4]. Details of the design and construction of MxWJ Model 5662-1, the mode-scale waterjet system, rotors, and propulsion nozzles, as well as additional photographs, are presented in Reference 3. Principal dimensions of the MxWJ stern design and arrangements are presented in Appendix A, Table A2, and in an associated sketch, Figure A1.

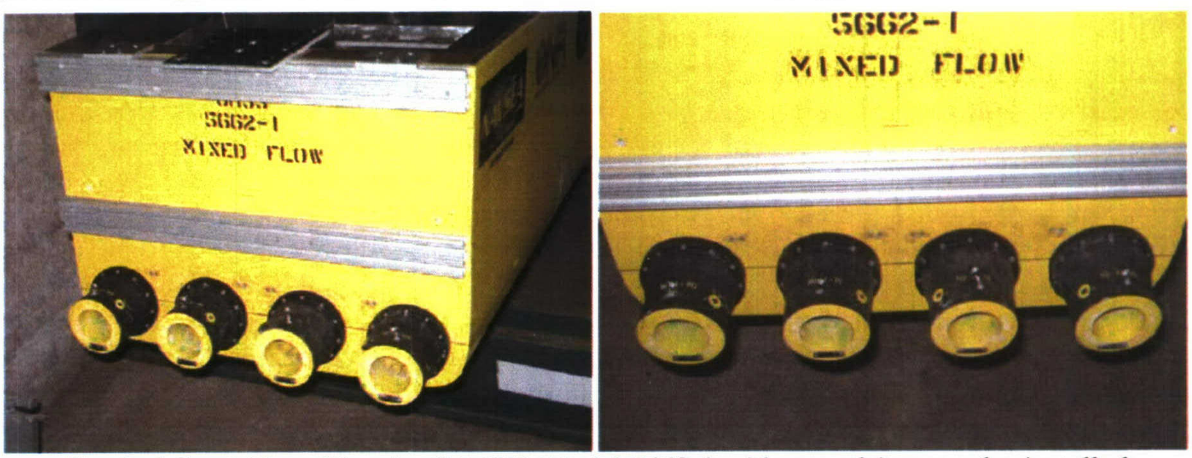

Fig. 1. Mixed-Flow Waterjet (MxWJ) Model 5662-1 with propulsion nozzles installed

The appended experiments to define the drag on MxWJ Model 5662-1 were conducted with the propulsion nozzles installed on the model, but with the waterjet inlets (intakes) covered by thin galvanized metal plates cut to the shape of the inlets, and affixed to the model with white fairing tape. When the inlets were opened for powering tests, right-angle ("L" shaped) pitot tubes were installed under the hull at waterjet station 1.

To produce turbulent flow along the model, turbulence stimulator studs of 1/8-inch diameter by 1/10-inch height, spaced 1 inch apart, were affixed to the model approximately 2-inches aft of the stem, and continuing down to and around the bulb approximately 2 inches aft of the FP.

Model 5662-1 resistance, powering, and initial waterjet priming tests were conducted at the JHSS hullform design displacement (DES) of 36,491 tons, static even keel (zero trim). Ship hydrostatic values corresponding to DES displacement are presented in Appendix A, Figure A2. In order to reduce the transom draft for the waterjet priming investigation, the model was ballasted to three incrementally lighter displacements, culminating in the final displacement required to submerge the rotor inlets to the 25% level. The tested model displacements corresponded to full-scale displacements of 34,620 tons (-5.1%), 32,755 tons (-10.2%), and 30750 (-15.7%). Static even keel was maintained for all displacement conditions.

Instrumentation

The testing of Model 5662-1 contained herein was conducted in parallel with resistance and powering tests in waves. The model installation on Carriage 2 was such that all testing techniques could be accommodated by a single model set-up and instrumentation.

Linear bearing, floating platform "Cusanelli" tow posts [Ref. 5], were utilized for both the forward and aft attachment points of the model to the carriage towing girder. To accommodate wave generation in Basin #2, it is required that the nominal water level be lowered by 30 inches. This necessitated that the model tow posts be attached to the Carriage 2 floating girder through 'box' extension brackets. Mechanical connections between the tow posts' instrumentation and the model were made through double-axis gimbal assemblies. The gimbal assemblies were mounted on two linear glide rails attached to the model, fore and aft, that were locked in a single longitudinal position throughout the testing contained herein.

In order to accommodate the test configurations at angles of yaw, the entire aft tow post assembly was suspended from a transverse sliding rail that allowed repositioning of the tow point perpendicular to the carriage towing girder. Yaw angles were defined as positive (+) bow-to-starboard, aft-to-port, as presented in Appendix A, Figure A3. To accommodate the yaw angles imparted, both the fore and aft gage sets were fastened through rotation couplings. The model yaw pivot axis was located at the centerline axis of the forward gage set installed on the forward tow post. The forward and aft gage sets rotated with the centerline of the model, so that model forces axes of measurement and sign conventions remained consistent in the model coordinate system, whether the model was set at angles of yaw or at zero yaw. For reference, the distance between the forward and aft gage sets (side force measurement points) was 147.5 inches model-scale. The installation in this fashion allowed for the model to be restrained in yaw, but free to pitch, heave, and roll, whether set at zero or non-zero static yaw angle.

Primary resistance (drag) measurement was collected using a DTMB 4-inch block gauge of 100-lbf. capacity. Primary drag force was measured at the forward tow post, at a position of ship station 5.44 (model-scale 91 inches forward of mid-ship station 10). A secondary drag force measurement was made at the aft tow post, positioned at ship station 13.44 (model-scale 57.5 inches aft of mid-ship station 10), using a 4-inch block gauge of 50-lbf. capacity. During testing, this drag gage was allowed to 'float' so as to impart minimal forces on the model. The drag forces measured at this point, were, however, incorporated into the overall drag measurement. Axis of measurement for both drag forces are along the model centerline.

Model forward and aft side force measurements were collected with DTMB 4-inch block gauges of 50-lbf. capacity. The forward side force measurement was made at the forward tow post and the aft side force measurement was made at the aft tow post. Axes of measurement for side forces are perpendicular to model centerline, with sign convention positive (+) force to Port and negative (-) force to Starboard.

Dynamic sinkage, defined as positive (+) downward, was measured by wire potentiometers located at the intersection of the deck line at Station 2 forward and Station 16 aft.

The thrust and torque on the four rotor shafts were measured with Kempf and Remmer's (K&R) model R31 dynamometers, of 22-lbf. thrust (T) / 35-in-lbf. torque (Q) capacity. To insure equivalent shaft rotational speed (RPM), all four rotor shafts were driven through 1:1 drive ratio "T" gearboxes and mechanically coupled so that all shafts were powered by a single 19 hP constant-torque electric drive motor. Shaft rotation for all four rotors was inboard-over-the-top. A single electronic pulse counter system was used to measure shaft RPM.

Calibration of all instrumentation was performed prior to the tests in the NSWCCD Code 5200 calibration lab by D. Mullinix (CSC contractor).

YAW EFFECTS ON WATERJET POWERING

In order to determine the effects of yaw angles on model waterjet powering, resistance and powering tests were conducted on MxWJ Model 5662-1 at angles of yaw equivalent to 0°, 1° and 3°, and at equivalent ship speeds of 20, 25, 30, and 36 knots. Photographs of Model 5662-1 during the yaw angle tests are presented in Appendix A, Figures A4 and A5.

Model-scale measurements of drag and fore and aft side forces were recorded for the three yaw angles during resistance (unpowered). Force values at 1° and 3° yaw were compared to the equivalent forces measured at zero yaw angle. Recorded drag and side force measurements are presented in Appendix A, Table A3 and Figure A6. For the model condition of largest yaw angle (3°) and the highest speed (36 knots) tested, the total side force recorded, expressed as a moment, was 759 ft-lbs, which resulted in an increase in drag of 2.53 lbs, corresponding to a 7.7% increase in model resistance.

Model powering tests were then conducted at the three angles of yaw. Model-scale rotor RPM was kept constant across the yaw angles, equivalent to the value determined during the standard propulsion tests (zero degree yaw), for the model operating at the ship propulsion point (model D_F applied). Model-scale measurements of drag and fore and aft side forces were again recorded at yaw and compared to the equivalent forces measured at zero yaw angle, presented in Appendix A, Table A4 and Figure A7.

During the powering tests, rotor force measurements of thrust, torque, and RPM were recorded for all four waterjets when at the yaw conditions, and compared zero angle case, presented in Appendix A, Table A5 and Figures A8 and A9. Model-scale rotor force measurements of thrust and torque at angles of yaw up to 3 degrees showed little variation compared to the equivalent forces measured at zero yaw angle. By way of example, the thrust and torque plots, for variations in yaw angle and speed, are presented for the port outboard rotor in Figure 2. In most cases, the thrust and torque measurements decreased when the model was placed at an angle of yaw. The testing technique was such that the model speed and rotor RPM were kept consistent between 0 degrees and 3 degrees yaw angle, therefore, the rotor advance coefficient was also constant. The variation in rotor forces recorded for 3° yaw when compared to zero degrees were in the range of +2.2% to -6.25% on Thrust, and 0% to -5.52% on Torque. Interestingly, even though starboard yaw angles were tested, the port side rotor measurements appeared to exhibit slightly greater variations across the tested yaw angles than did the corresponding starboard side measurements.

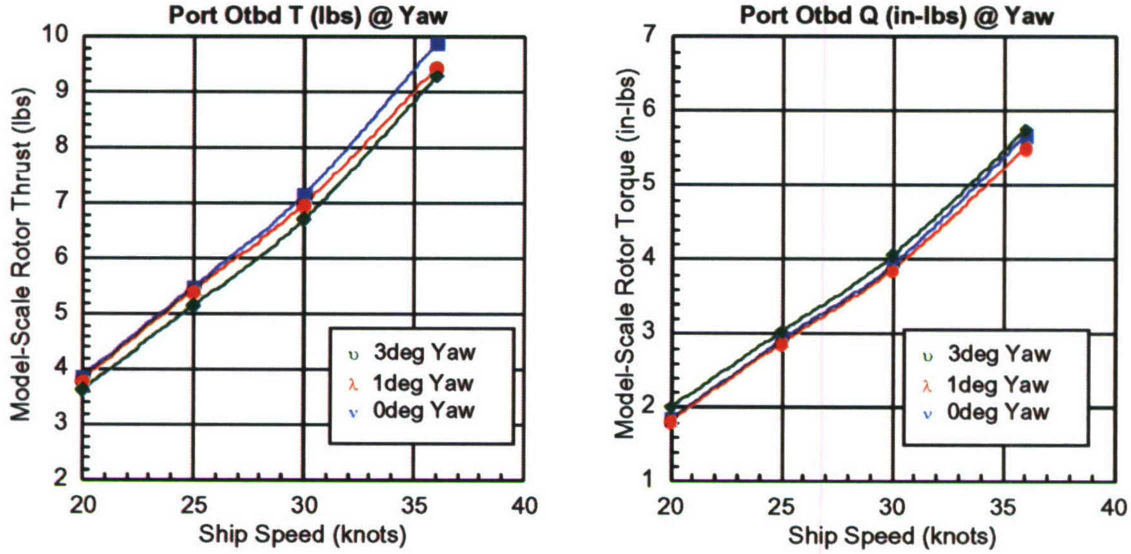

Fig. 2. Example model-scale rotor force variations due to yaw angle, port outboard rotor

Model Test Uncertainties - Resistance & Powering Measurements

Time constraints of the present testing series on the MxWJ Model 5662-1 did not allow for a determination of measurement uncertainties on this model. However, as aforementioned, the MxWJ was the second of two waterjet model variants of the JHSS parent hull, the previous being the Axial Waterjet (AxWJ) Model 5662. Due to the similarity of the two hulls, and the use of the identical rotors, measurement instrumentation, electronics, and testing techniques, it can be assumed that the measurement uncertainty between the two hulls would be similar.

Measurement uncertainties were determined on AxWJ Model 5662 for the quantities of model speed, and hull resistance, and for combined inboard and outboard shafts quantities of shaft thrust, torque, and rotational speed (RPM), presented by Cusanelli and Carpenter [Ref. 3]. Overall uncertainties were determined by combining bias and precision limits using the root-sum-square (RSS) method for a 95 percent confidence level. The values for torque and RPM were then used to determine the uncertainty in the calculation of delivered power. The determined uncertainties for measured model delivered power reflect the combined measurement uncertainties of eight model quantities, shaft torque and RPM, for each of four shafts.

Resistance measurement uncertainties, at 25 and 36 knots, were determined to be $\pm$0.85% and $\pm$0.33% of the measured nominal mean values, respectively. Likewise, the model scale delivered power measurement uncertainties were $\pm$1.72% and $\pm$1.05%, at 25 and 36 knots.

SUBMERGENCE EFFECTS ON WATERJET PRIMING

Tests were conducted on MxWJ Model 5662-1 to investigate the effects of variations in model transom depth, and by extension the submergence of the waterjet pump inlet, on the priming of the waterjets. Observations were made visually as to the state of fluid flow through the waterjet, and assessments were made as to the condition of waterjet priming, at four different transom depths and three different model speeds. In order to reduce the transom draft during the priming tests, the model was ballasted, even keel, to incrementally lighter displacements.

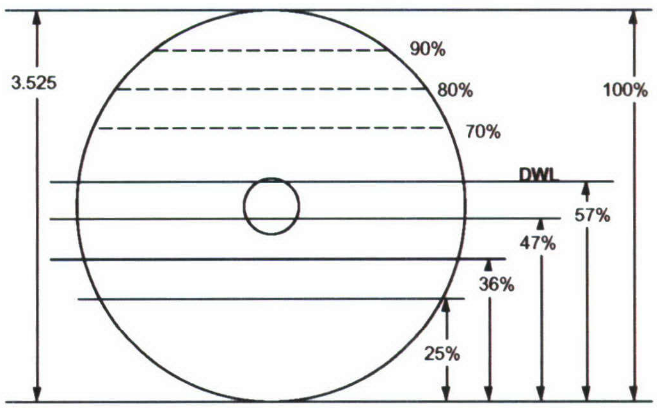

Fig. 3. Model 5662-1 pump inlet diagram showing submergence criteria definition

The criterion for waterjet pump inlet submergence was defined by the percent of the inlet diameter below the still waterline. The diameter of the model-scale pump inlet was 3.535 inches. When at the design waterline (DWL), 57% of the model inlet was submerged, by definition. (The waterjet original design criterion was for a minimum of 50% submergence.) The additional waterjet submergences tested, as depicted in Figure 3, were 47%, 36%, and a minimum submergence of 25%.

Three different model speeds were tested, 0, 0.5, and 1 knot (corresponding to 0, 2.9, and 5.8 knots full-scale), to determine if there was any effect of speed on the priming of the pumps.

Visual observations in regards to priming were made at the waterjet nozzles. The assumption was made that the priming level observed at the nozzles would be representative of the overall priming state of the waterjet. The definition of priming level at the nozzles was the equivalent criterion as that used for the waterjet pump inlet submergence, refer to Figure 3. Priming was recorded as the percent of the nozzle diameter filled with waterjet exhaust flow, up through and including 100%, which by definition was considered fully primed. Photographs depicting the different levels of waterjet priming, as observed at the nozzles, are presented in Appendix A, Figure A10. The sole exception to this criterion was for priming level recorded as 95%. For these cases, the nozzle appeared to be essentially full, but the waterjet exhaust flow was observed to have a sharp downward angle immediately aft of the nozzle trailing lip. It was decided by the test engineers, for 100% primed to be recorded, the waterjet exhaust flow should be observed to project perpendicular to the nozzle, immediately aft of the nozzle exit.

The MxWJ Model 5662-1 waterjet nozzle priming levels as a function of pump inlet submergence, with variations in rotor RPM and model speed, as tested, are presented in Appendix A, Table A6 and Figure A11. Also presented in Figure A12 is the priming data re-plotted as a function of model speed.

While reducing the static pump inlet submergence from the DWL value of 57%, to 47%, and 36%, did effect the relationship between rotor RPM and nozzle priming level, the effect was not substantial. On average, each nominal 10% reduction in pump inlet submergence increased the model-scale rotor RPM for equivalent nozzle priming level by 100 RPM (~18 RPM ship-scale). However, this relationship did not hold true for the minimum 25% pump inlet submergence level, where substantial increases in rotor RPM, sometimes as much as three times the previous RPM value, was required for equivalent nozzle priming level.

Essentially the same results were exhibited for the influence of model speed on the pump priming. The increases in model-speed from 0 to 0.5 knots, and then 1.0 knots (ship speeds of 0, 2.9, 5.8 knots) had only a small influence on waterjet priming. On average, each 0.5 knot increase in model speed reduced the model-scale rotor RPM by 100 for equivalent nozzle priming level. Again, the exception being the test at the 25% pump inlet submergence level, where, at the higher RPM values, the influence of speed amounted to approximately a 200 RPM reduction in rotor speed for equivalent nozzle priming level.

The MxWJ Model 5662-1 waterjet nozzle priming level data is summarized in Figure 4, where the model-scale rotor RPM to attain primed waterjets (100% level) is presented for the tested static pump inlet submergences and model speeds. It appears that waterjets will be essentially self-priming for static pump inlet submergences of approximately 35% or higher. For these three static pump inlet submergences, the range for incipient full priming (100%) was 500 to 800 RPM model-scale. In terms of ship powering, these rotor RPMs are what would be required to propel the ship at approximately 11 to 13 knots. For the minimum tested static pump inlet submergence of 25%, pump priming was not attained for the bollards (0 speed) or 0.5 knots tests, and at the 1.0 knot model speed a substantial increase to 2200 RPM was required to attain pump priming. This value is equivalent to propelling the ship at 38 knots.

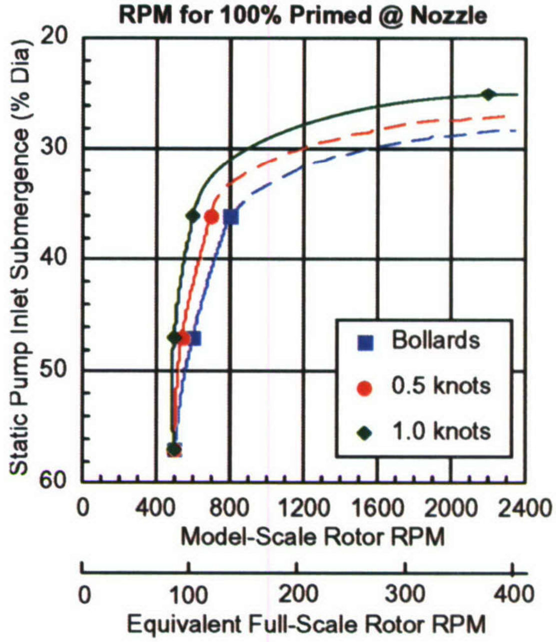

Fig. 4. Model-scale rotor RPM to attain primed waterjets at tested pump inlet submergences and model speeds

Trends in the data of Figure 4 indicate that the initial waterjet design criterion of retaining 50% of the rotor submerged was conservative, and could be relaxed somewhat, possibly to the 35% submergence level, for future designs. It also indicates that a static pump inlet submergence as low as 25% appears to be at a level where pump self-priming may not occur at reasonable rotor RPMs.

Additional observations, made during the testing at a model speed of 1.0 knots for the 25% pump inlet submergence level, indicated that once pump priming had been attained at the extremely high model rotor RPM, it could then be reduced to as low as 400 RPM before the loss of the 100% primed level. A rotor RPM of only 400 is below the RPM value observed for incipient priming for any of the tested pump inlet submergences. This observation appears to indicate that if pump priming is induced by some external means, the waterjet should retain its primed state down to fairly low rotor RPMs, even when the initial pump inlet submergence is as low as the 25% level.

CONCLUSIONS

This report is a partial documentation a series of model-scale experiments conducted on Mixed-Flow Waterjet (MxWJ) Model 5662-1, a waterjet propelled variant of the Joint High Speed Sealift (JHSS). Data and evaluations are presented from initial investigations into: (1) The effects of model yaw angles on waterjet powering; and (2) The effects of variations in the submergence of the waterjet pump inlet on the priming of the waterjets.

Model-scale rotor force measurements of thrust and torque at angles of yaw up to 3 degrees showed little variation compared to the equivalent forces measured at zero yaw angle. In most cases, the thrust and torque measurements decreased when the model was placed at an angle of yaw. The variation in rotor forces recorded for 3° yaw when compared to zero degrees were in the range of +2.2% to -6.25% on Thrust, and 0% to -5.52% on Torque. Interestingly, even

though starboard yaw angles were tested, the port side rotor measurements appeared to exhibit slightly greater variations across the tested yaw angles than did the corresponding starboard side measurements.

The submergence of the waterjet pump inlet was varied from the design waterline, where 57% of the inlet was submerged, to a minimum submergence of 25% level. Visual observations as to the state of fluid flow through the waterjets indicated that the initial waterjet design criterion of retaining 50% of the rotor submerged was conservative, and could be relaxed somewhat, possibly to the 35% submergence level, for future designs. However, pump inlet submergence as low as 25% appears to be at a level where pump self-priming may not occur at reasonable rotor RPMs.

Additional observations indicated that once pump priming had been attained, the model rotor RPM could be reduced substantially before the loss of the 100% primed level. This observation appears to indicate that if pump priming is induced by some external means, the waterjet should retain its primed state down to fairly low rotor RPMs, even if the initial pump inlet submergence is as low as the 25% level.

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The author would also like to acknowledge the following for their contributions: B. Metcalf (NSWCCD Code 5200) and D. Mullinix (CSC).

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APPENDIX A

Model 5662-1 Data and Analysis

APPENDIX A FIGURES

APPENDIX A TABLES

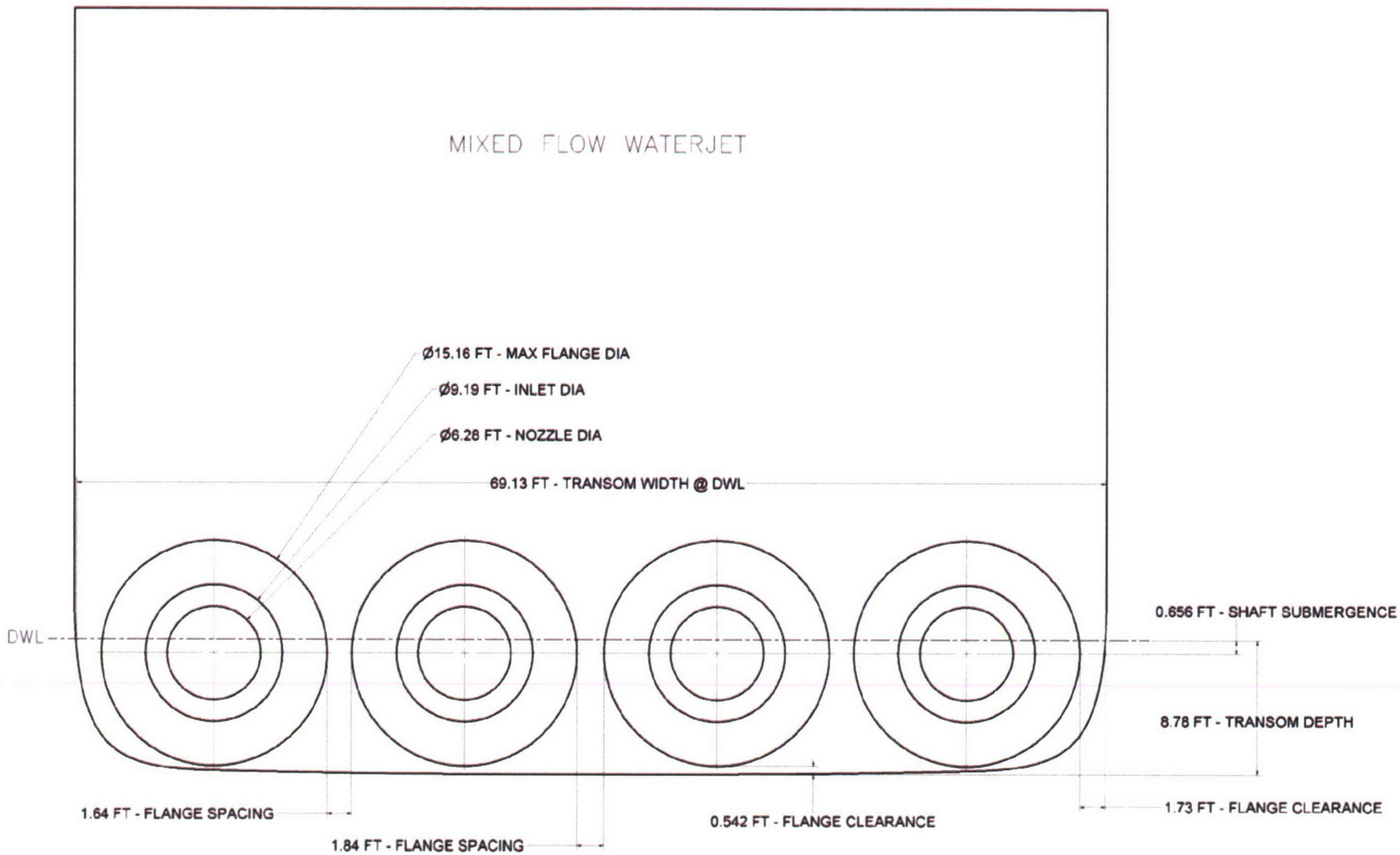
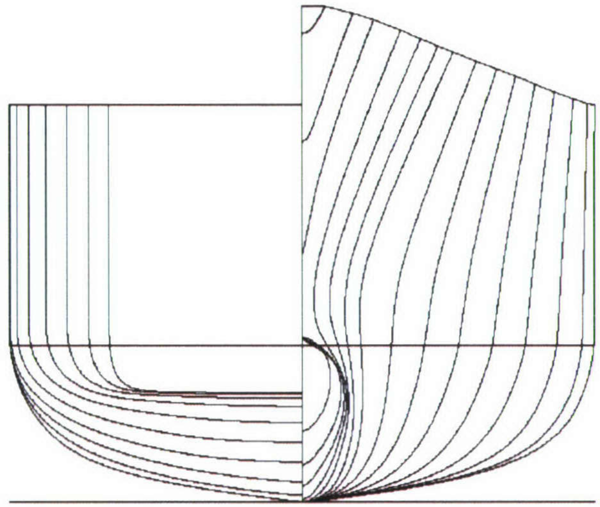


Fig. A1. MxWJ Model 5662-1 sketch of transom and waterjet arrangement

JHSS Mixed Flow Waterjet Hull Gooseneck Bulb 06/10/2006



PRINCIPAL DIMENSIONS

LENGTH (LBP)	=	950.51 ft	(289.71 m)
LENGTH (LWL)	=	980.20 ft	(298.77 m)
BEAM (B_X)	=	104.75 ft	(31.93 m)
DRAFT (T_X)	=	27.83 ft	(8.48 m)
TRIM (+Bow)	=	0.00 ft	(0.00 m)
DISPLACEMENT	=	36491.0 T	(37075. t)
WETTED SURFACE	=	97372 sqft	(9046. sqm)

NONDIMENSIONAL COEFFICIENTS

C_B	= 0.447	C_{VP}	= 0.637	L_E/LWL	= 0.530
C_P	= 0.560	C_{VPF}	= 0.802	L_P/LWL	= 0.000
C_{PF}	= 0.497	C_{VPA}	= 0.860	L_R/LWL	= 0.470
C_{PA}	= 0.635	C_S	= 2.753	FB/LWL	= 0.502
C_{PE}	= 0.520	LWL/B_X	= 9.358	FF/LWL	= 0.567
C_{PR}	= 0.605	B_X/T_X	= 3.764	$100C_\nabla$	= 0.136
C_X	= 0.797	A_T/A_X	= 0.237	$\Delta/(.01LWL)^3$	= 38.7
C_{WP}	= 0.701	B_T/B_X	= 0.659	i_E	= 3.80
C_{WPF}	= 0.494	T_T/T_X	= 0.302	i_R	= 4.46
C_{WPA}	= 0.924	A_B/A_X	= 0.116	i_B	= 0.85

MODEL SCALE DATA

SCALE RATIO	=	34.121	
LENGTH (LBP)	=	27.86 ft	(8.49 m)
LENGTH (LWL)	=	28.73 ft	(8.76 m)
BEAM (B_X)	=	3.07 ft	(0.94 m)
DRAFT (T_X)	=	0.82 ft	(0.25 m)
DISPLACEMENT	=	2001.1 lbs	(0.91 t)
WETTED SURFACE	=	83.64 sqft	(7.77 sqm)

Fig. A2. MxWJ hydrostatic calculations, design displacement

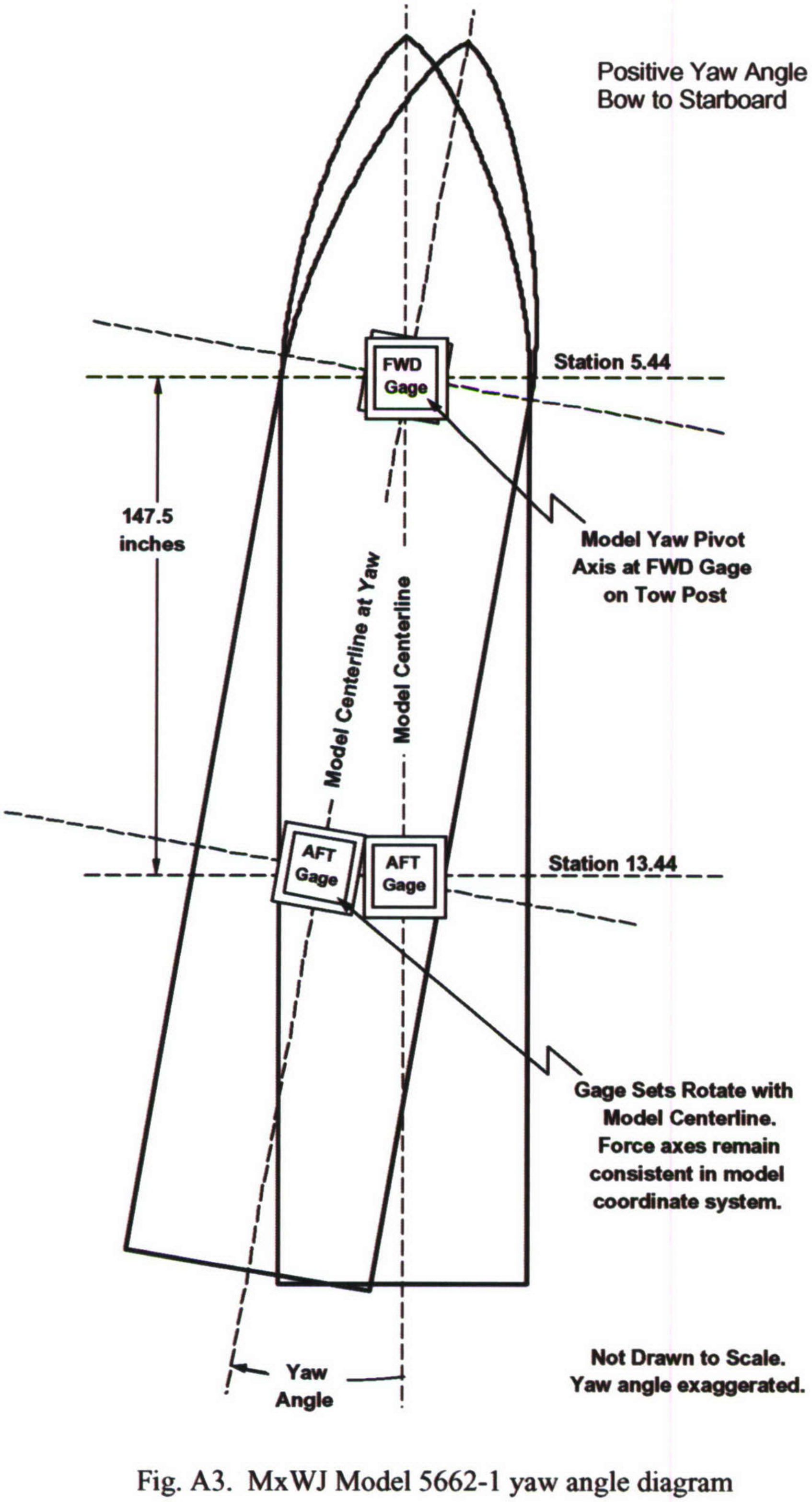


Fig. A3. MxWJ Model 5662-1 yaw angle diagram

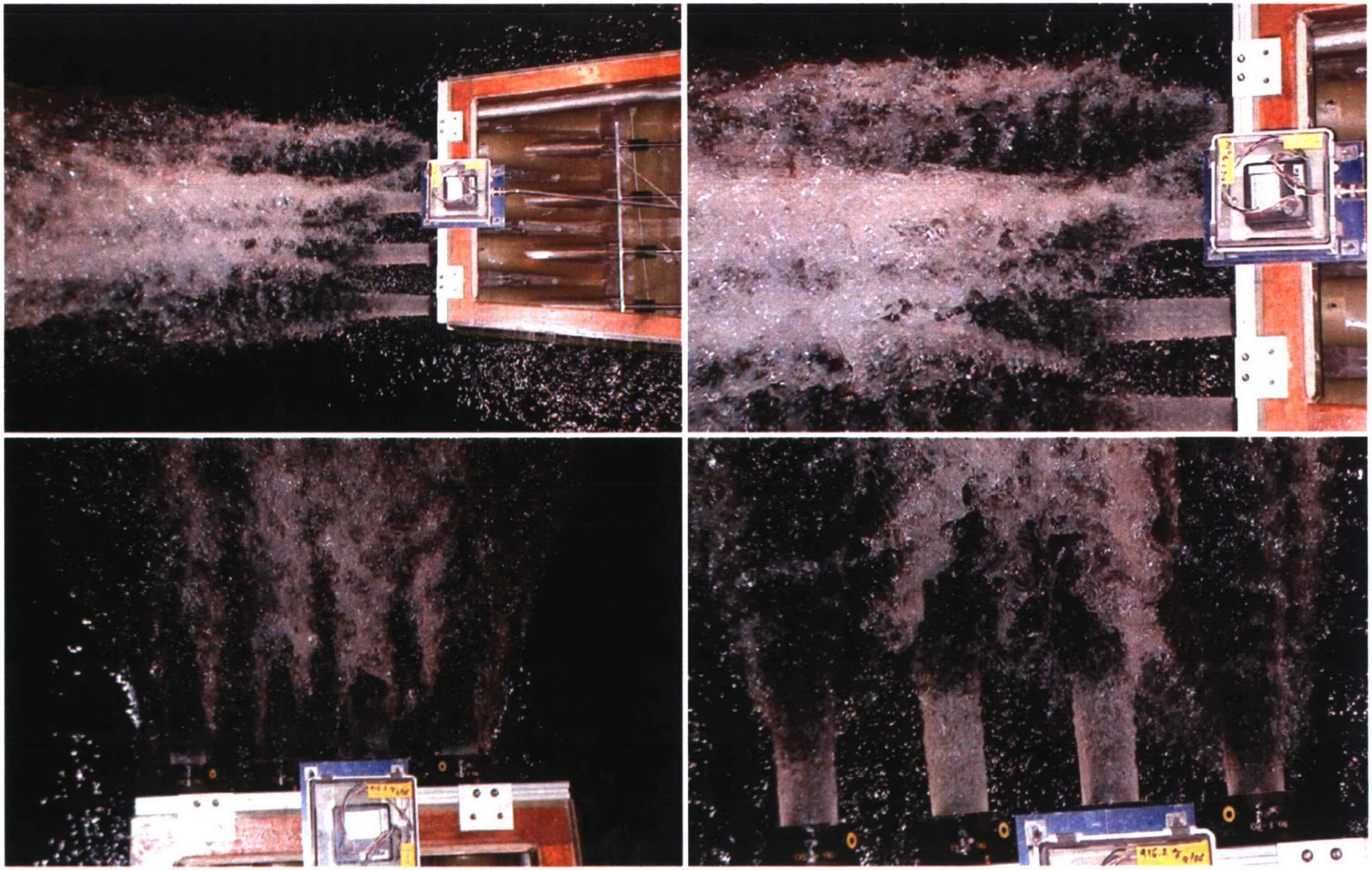


Fig. A4. MxWJ Model 5662-1 photos, powered at 1 degree yaw to starboard

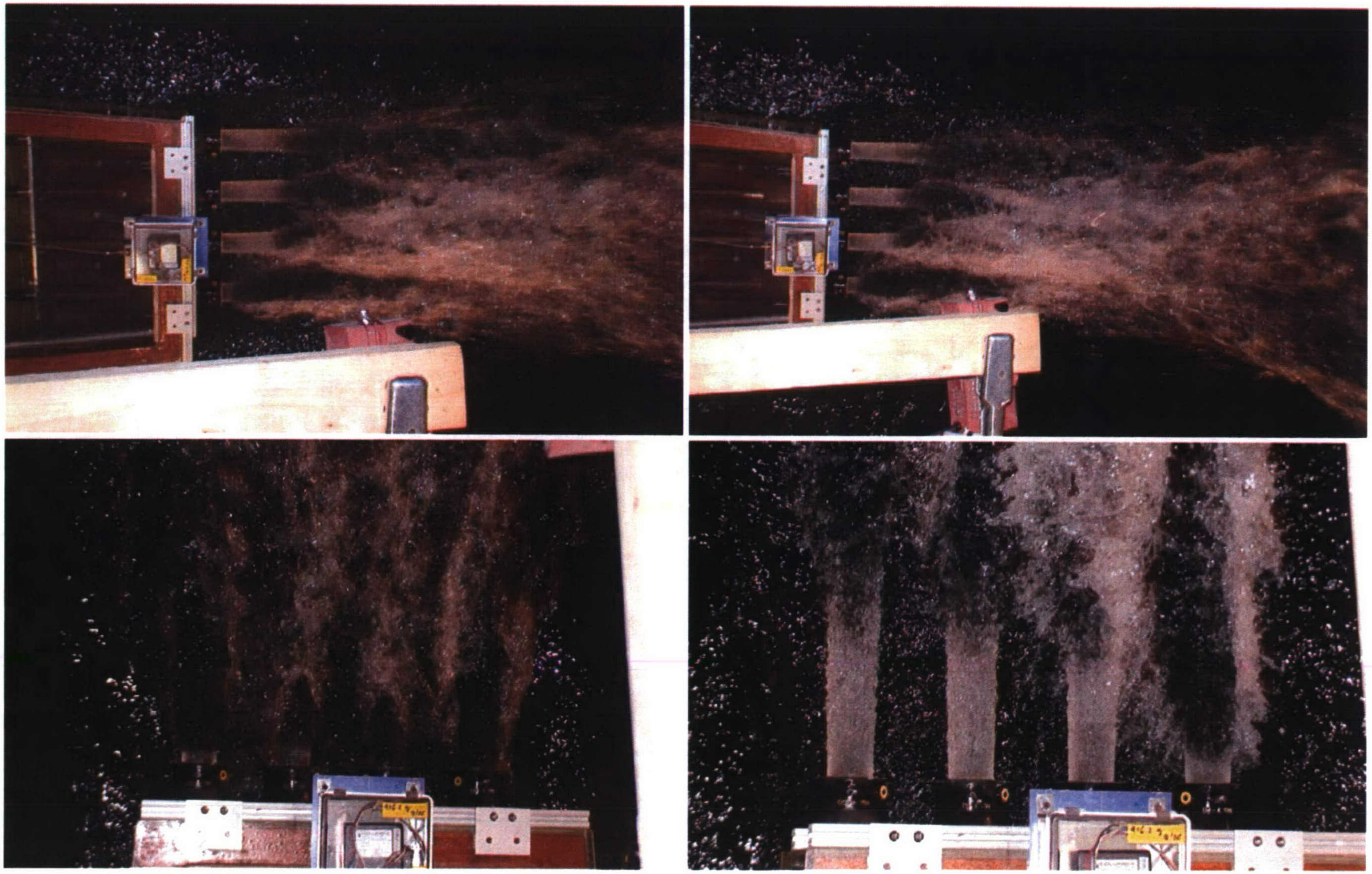


Fig. A5. MxWJ Model 5662-1 photos, powered at 3 degrees yaw to starboard

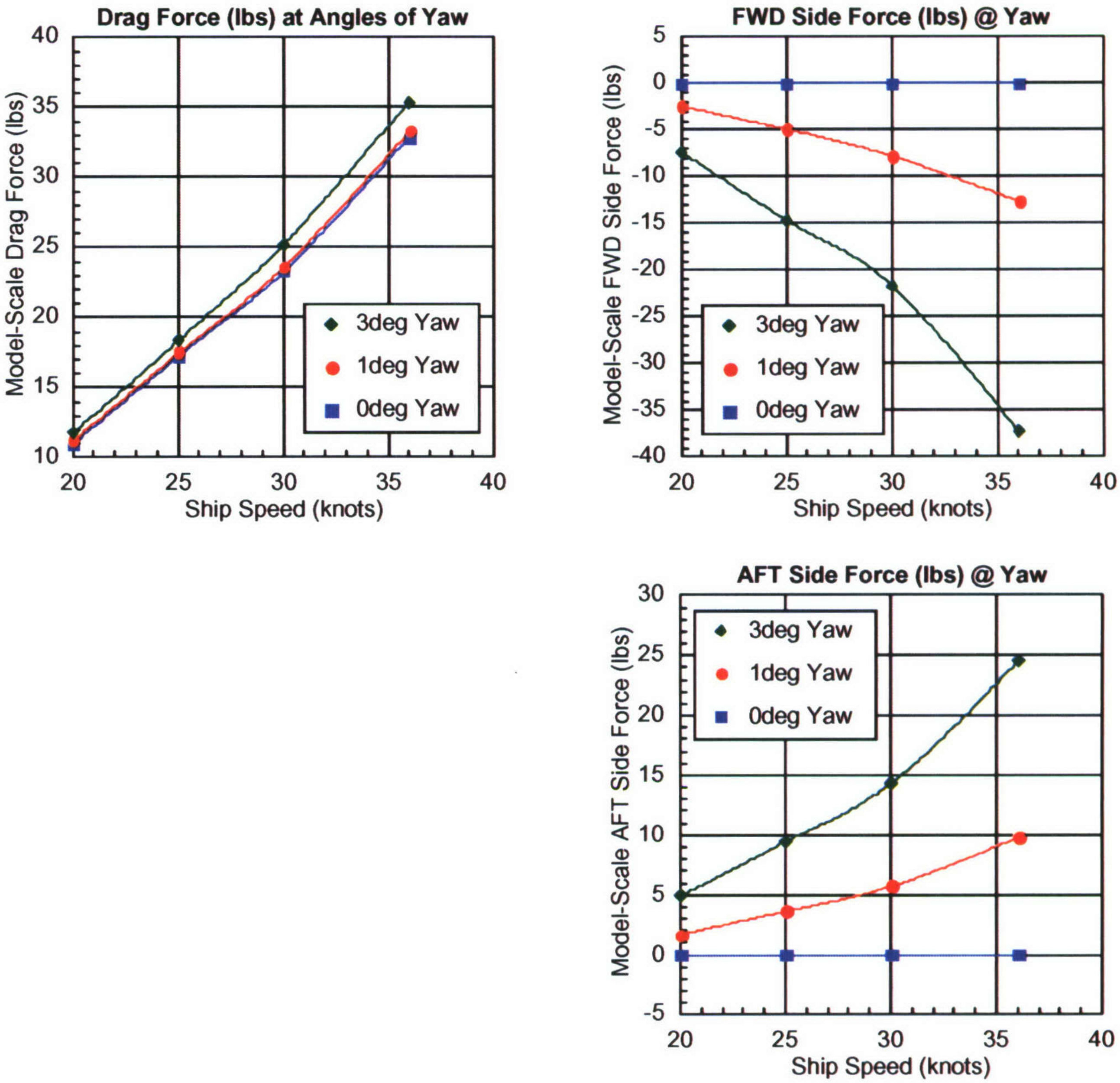


Fig. A6. MxWJ Model 5662-1, drag and side force measurements, resistance tests at angles of yaw

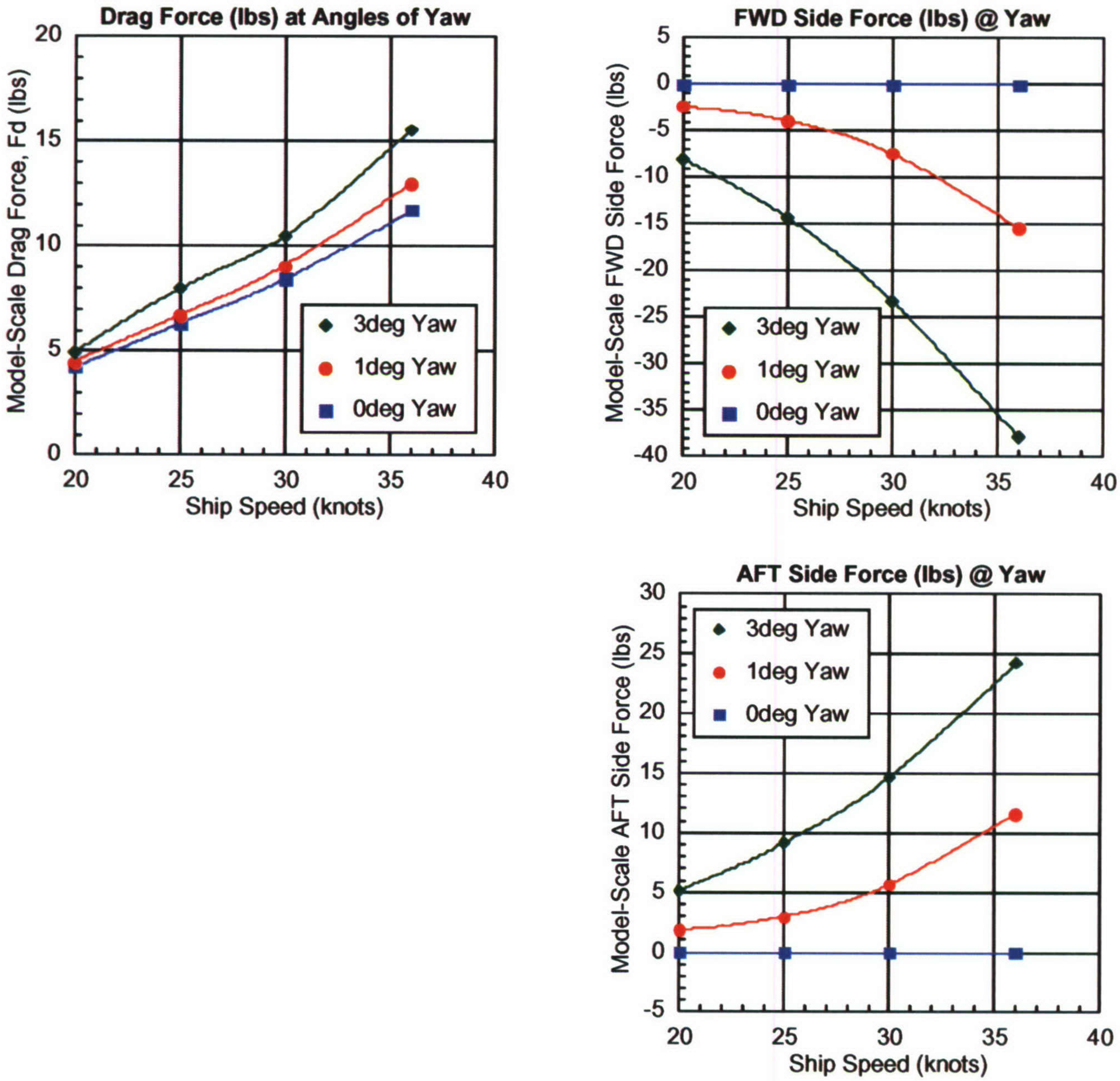


Fig. A7. MxWJ Model 5662-1, drag and side force measurements, powering tests at angles of yaw

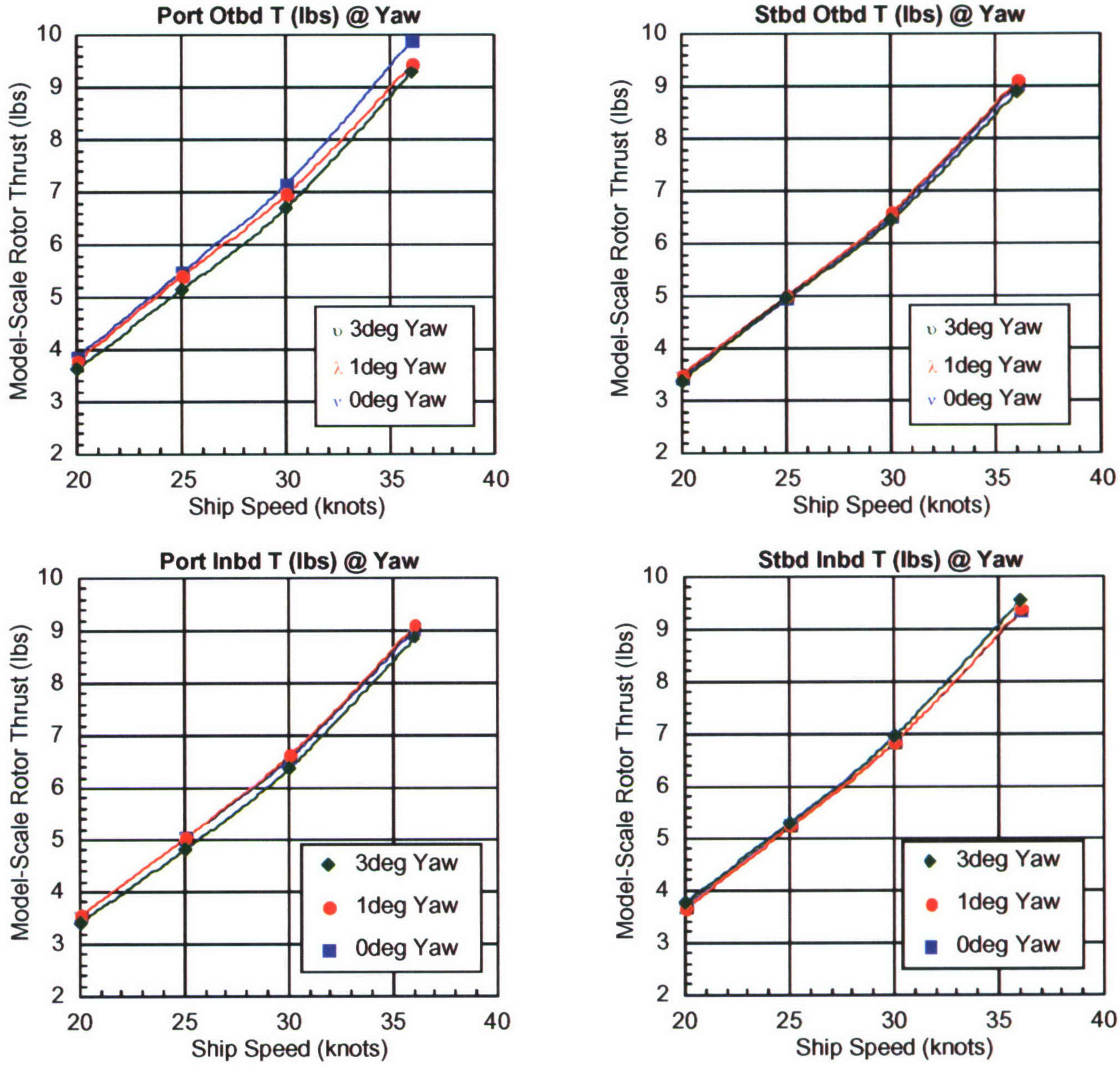


Fig. A8. MxWJ Model 5662-1, rotor thrust measurements, powering tests at angles of yaw

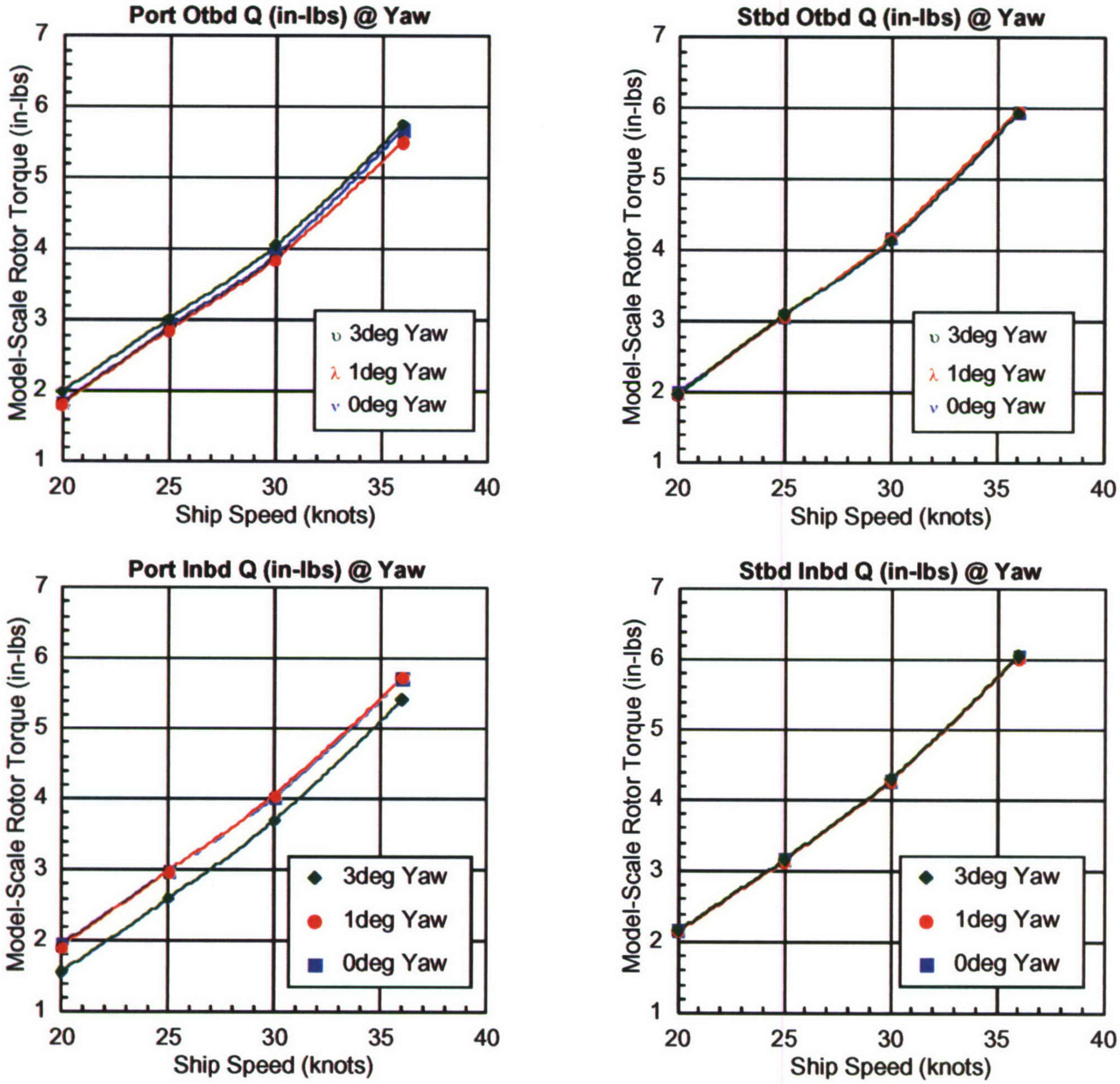
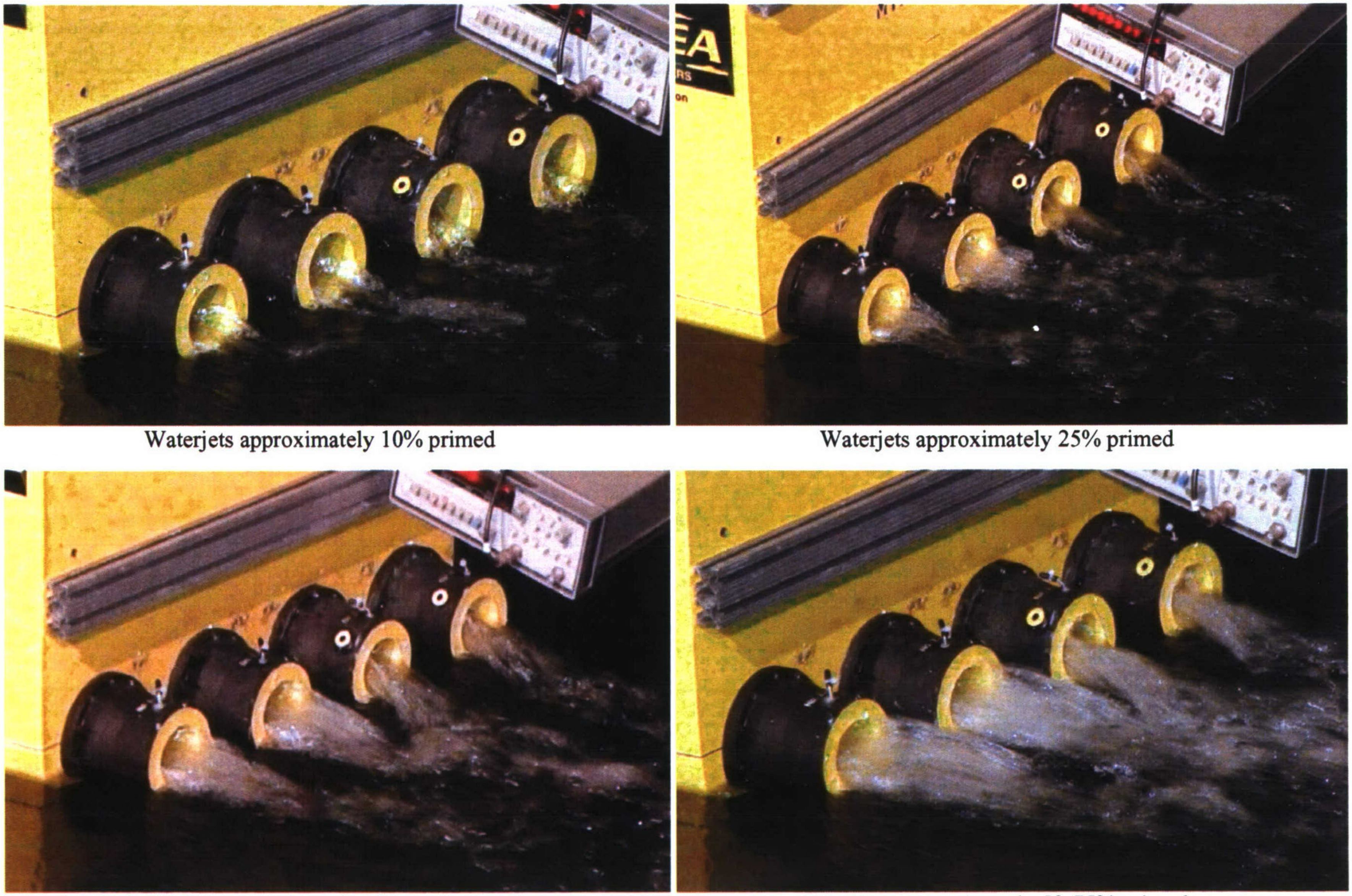


Fig. A9. MxWJ Model 5662-1, rotor torque measurements, powering tests at angles of yaw



Waterjets approximately 10% primed

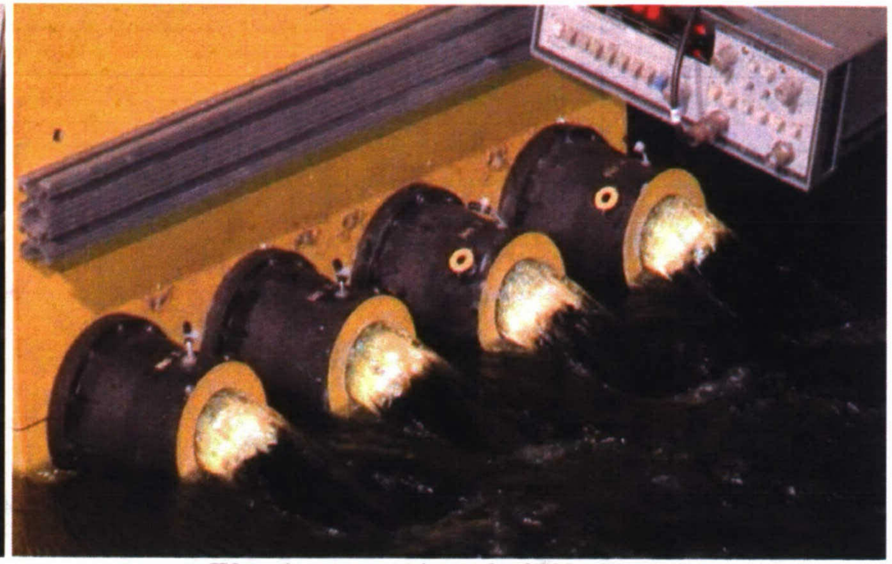
Waterjets approximately 25% primed

Waterjets approximately 50% primed

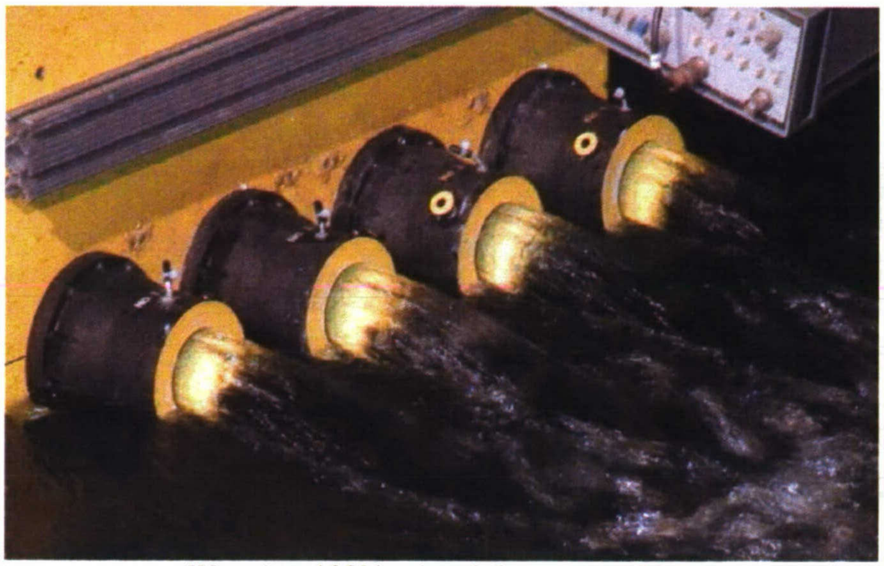
Waterjets approximately 50-75% primed

Fig A10. MxWJ Model 5662-1 photos, waterjet nozzles at various levels of priming

Waterjets approximately 80-90% primed



Waterjets approximately 95% primed



Waterjets 100% primed (low rotor RPM)

Waterjets 100% primed (higher rotor RPM)

Fig A10. MxWJ Model 5662-1 photos, waterjet nozzles at various levels of priming - continued

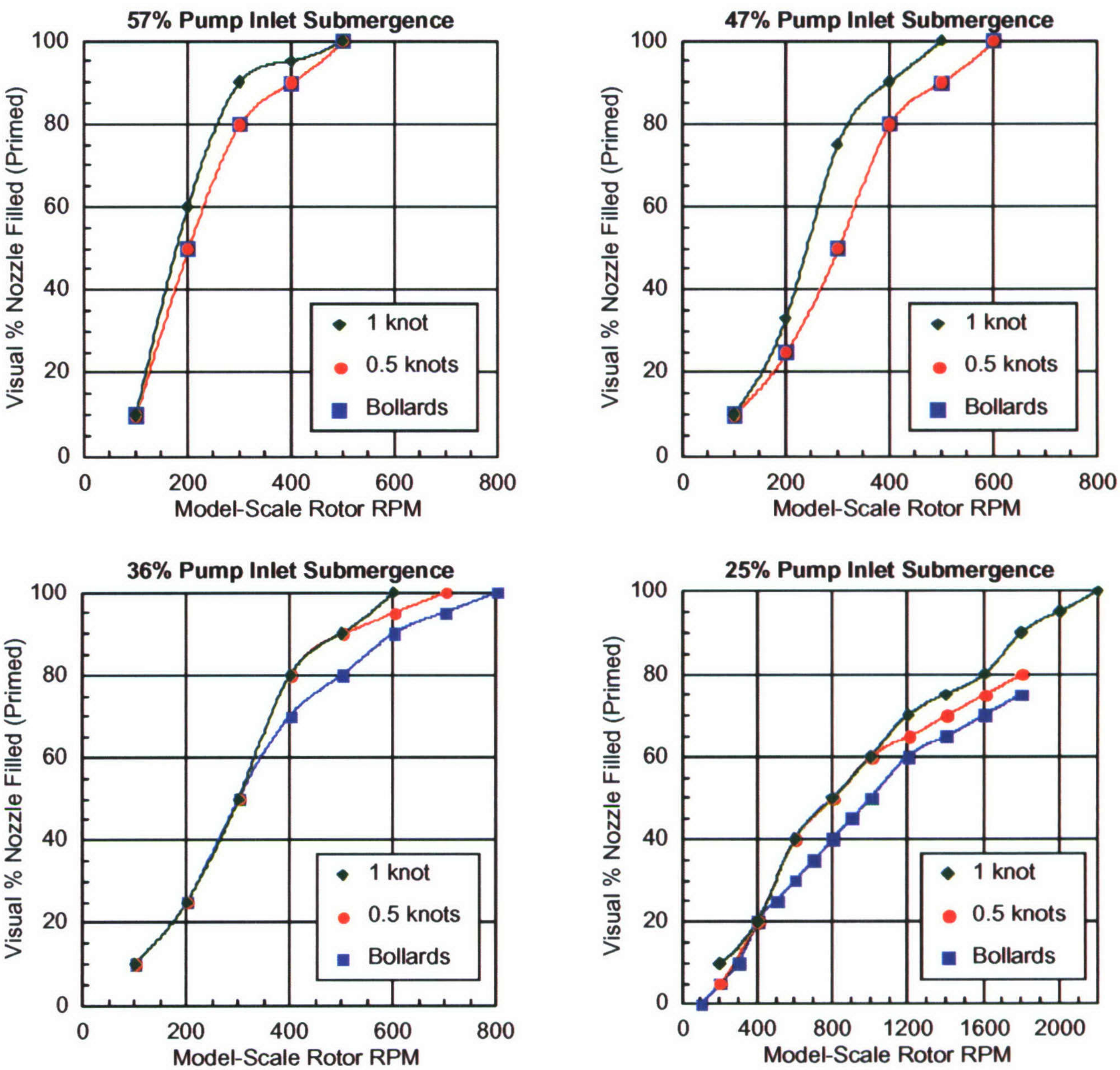


Fig. A11. MxWJ Model 5662-1, waterjet nozzle priming level as a function of pump inlet submergence, with variations in rotor RPM and model speed

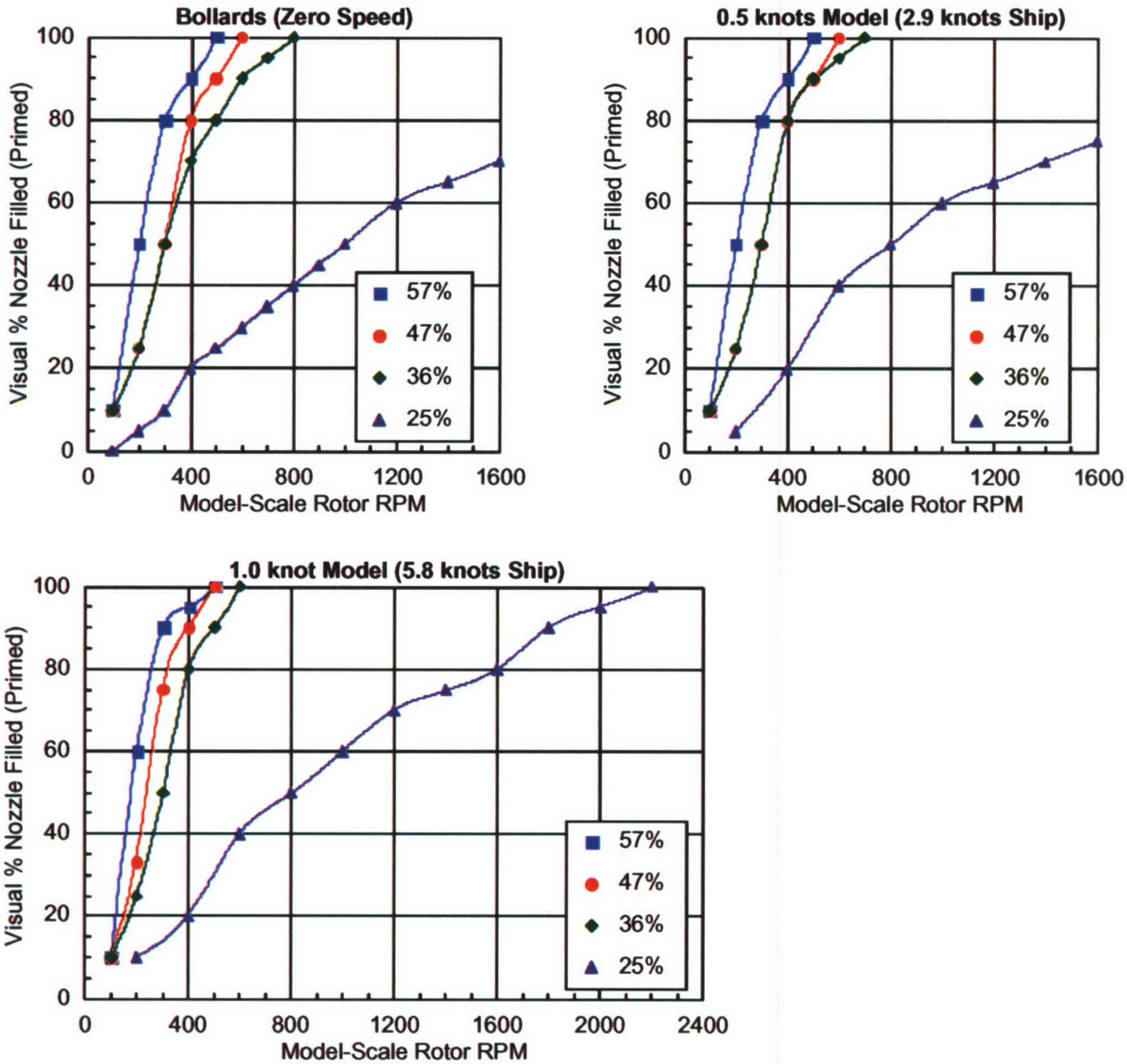


Fig. A11. MxWJ Model 5662-1, waterjet nozzle priming level as a function of model speed, with variations in pump inlet submergence and rotor RPM

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Table 1. Test Agenda, MxWJ Model 5662-1, yaw and waterjet priming tests

Day	DATE	TEST	DISP	TASK	GLIDE	WAVES	λ/LOA	ζ/λ	VS (knots)	Req. Hrs
Mon	9-Jul	51	-	Block gage removed. Time constrains necessitate calibration of new gage rather than repair of existing gage. New Block Gage calibrated, installed, checked out.						2
		52	DES	Calm Water Resistance - New block gage	Locked	Calm	N/A		25, 36	1
		53	DES	INCREASED Resistance @ 36 knots in Regular Waves (continuation of Test 50)	Locked	REGULAR	0.966	1/100 1/75 1/65	36	3
		54	DES	Baseline PE Test (0) for Yaw Study	Locked	Calm	N/A		20,25,3 0,36	3
		55		Yaw angle 1 , Unpowered (PE)						
		56		Yaw angle 3 , Unpowered (PE)						
		-	LITE	Removal of weights waterborne. Ballast to LITE dynamic waves conditions.						2
		57	LITE	Calm Water Resistance	Locked	Calm	N/A		25, 36	1
Tue	10-Jul	58	LITE	SS6 Random Waves Sampling, Wavemaker adjustments.	Locked	RANDOM	SS6		0	1
				ADDED Resistance, Random Waves SS6. Data collection for 60 minutes full-scale equivalent.					25, 36	7
		59	LITE	Calm Water Check Test	Locked	Calm	N/A		25, 36	1
		-	LITE	Remove Waterjet Inlet Covers and Nozzle Plugs (Waterborne)						1
		60 61	LITE	Resistance with Waterjet Inlets Open, w/wo rotors rotating.	Locked	Calm	N/A		25, 36	2
Wed	11-Jul	62	LITE	Calm Water Power, Ship Propulsion Point and Model Self-Propulsion (DF=0)	Locked	Calm	N/A		25, 36	2
		63	LITE	Calm Water Power, Model Self-Propulsion	Free to Surge	Calm	N/A		25, 36	1
		64	LITE	SS6 Random Waves Sampling, Wavemaker adjustments.						1
				ADDED Power, Model Self-Propulsion. 60min equ at each speed.	Free to Surge	RANDOM	SS6		25, 36	7
Thur	12-Jul	65	LITE	SS6 Random Waves Sampling, Wavemaker adjustments.	Locked	RANDOM	SS6		0	1
				ADDED Power, Model Self Propulsion (DF=0). 60min equ at each speed.					25, 36	6.5
		-	DES	Add weights waterborne. Ballast back to DES dynamic waves conditions.						1
		66	DES	Calm Water Power, Ship Propulsion Point.	Locked	Calm	N/A		25, 36	4
				Baseline Powered Test (0) for Yaw Study					20,25,3 0,36	
		67		Yaw angle 1 , Powered (PD)						
Fri	13-Jul	68		Yaw angle 3 , Powered (PD)						2
		69	DES	Calm Water Power, Model Self-Propulsion	Free to Surge	Calm	N/A		25, 36	2
		70	DES	SS6 Random Waves Sampling, Wavemaker adjustments.	Free to Surge	RANDOM	SS6		0	1
				ADDED Power, Model Self-Propulsion. 60min equ at each speed.					25, 36	7
Test Week 3				12-hour days						
Mon	16-Jul	71	DES	INCREASED Power, Model Self-Propulsion 25 knots. Max ARO Wavelength.	Free to Surge	REGULAR	0.882	1/150 1/125 1/100 1/75 1/60	25	12
				INCREASED Power, Model Self-Propulsion 36 knots. Max ARO Wavelength.			0.966	1/150 1/125 1/100 1/75	36	
Tue	17-Jul	72	DES	SS6 Random Waves Sampling, Wavemaker adjustments.	Locked	RANDOM	SS6		0	1
				ADDED Power, Model Self-Propulsion Point. 60min equ at each speed.					25, 36	8
		73	DES	ADDED Power, Ship Propulsion Point.	Locked	RANDOM	SS6		25	3
				SS6 Random Waves Sampling, Wavemaker adjustments.					0	1
				ADDED Power, Ship Propulsion Point.	Locked				36	4
Wed	18-Jul	74	DES	Calm Water Powering Repeat Check Test, Ship Propulsion Point.	Locked	Calm	N/A		25, 36	2
		75	DES	Calm Water Powering Repeat Check Test, Model Self-Propulsion Point.	Locked	Calm	N/A		25, 36	2
		-	-	Modify model and equipment as required for Waterjet Priming Observations						2
Thur	19-Jul	-	-	Observations of Waterjet Priming. Nozzle submergence, rotor RPM, and speed variations.	Draft (inch)	Δ Draft (inch)	Submergence @ Pump Inlet (inch)	(%)	Speed (kts)	
		76	DES	Baseline Draft Condition for Priming	9.744	0	1.99	0.57	0, 3, 6	6
		77		Condition 2: ~102lbs removed (3 bricks)	9.397	-0.347	1.65	0.47		
		78		Condition 3: ~204lbs removed (6 bricks)	9.042	-0.355	1.29	0.36		
		79		Condition 4: ~314lbs removed (9 bricks + 8lbs)	8.678	-0.364	0.93	0.25		
Fri	20-Jul	-	-	DERIG: Model and Carriage						

Table A2. Principle dimensions of the MxWJ stern design and arrangements

	Full-Scale Design	Model-Scale Installation
Pump Inlet Diameter (ft)	9.19	10.02
[1] Ratio: WJ Max Dia to Pump Inlet Dia	1.65	1.21
[1] Waterjet Maximum Diameter (ft)	15.16	12.16
Nozzle Exit Diameter (ft)	6.28	6.28
[2] Flange Clearance, Minimum Stipulated (ft)	1.64	n/a
Flange Clearance, Inboard-to-Outboard Jets, port and starboard (ft)	1.64	n/a
Flange Clearance, Inboard Jets (ft)	1.84	n/a
[2] Pump Inlet Spacing, Inboard-to-Outboard Jet, port and starboard, center-to-center (ft)	16.80	16.80
Pump Inlet Clearance, Inbd-to-Otbd (ft)	7.61	6.77
Pump Inlet Clearance, Inbd-to-Otbd, Percent Pump Inlet Dia (%)	83%	68%
Pump Inlet Spacing, Inboard Jets (ft)	17.00	17.00
Pump Inlet Clearance, Inboard Jets (ft)	7.81	6.97
Pump Inlet Clearance, Inbd, Percent Pump Inlet Dia (%)	85%	70%
Minimum Transom Width, WJ MAX diam plus stipulated clearances (ft)	67.19	n/a
Transom Width (ft)	69.13	69.13
[3] Waterjet Submergence, Minimum Stipulated, Percent Pump Inlet Diameter (%)	50%	n/a
Waterjet Submergence, Minimum Stipulated (ft)	4.59	n/a
Shaft Centerline Submergence, below DWL (ft)	0.66	0.66
Waterjet Submergence (ft)	5.25	5.67
Percent Inlet Diameter Submerged (%)	57.1%	56.5%
[3] Transom Depth (ft)	8.78	8.78
*Flange-to-Hull Clearance (ft)	0.54	n/a
Transom Wetted Surface Area (ft^2)	577.3	577.3
Transom Volume aft of Station 15 (ft^3)	208,064	208,064

Table dimensions are Full-Scale.

Values correspond to design displacement (DES) of 36,491 tons

Table A3. MxWJ Model 5662-1, drag and side force measurements, resistance tests at angles of yaw

Drag & Side Forces at Angles of Yaw (UNPOWERED)									
	Drag Force (lbs)			FWD Side Force (lb)			AFT Side Force (lb)		
VS (knots)	0deg Yaw	1deg Yaw	3deg Yaw	0deg Yaw	1deg Yaw	3deg Yaw	0deg Yaw	1deg Yaw	3deg Yaw
20	10.98	11.30	11.80	0.00	-2.41	-7.37	0.00	1.65	4.90
25	17.27	17.54	18.40	0.00	-4.90	-14.69	0.00	3.60	9.43
30	23.32	23.61	25.23	0.00	-7.84	-21.70	0.00	5.75	14.30
36	32.82	33.31	35.35	0.00	-12.59	-37.27	0.00	9.84	24.49

	Drag Force (lbs)		
VS (knots)		Δ vs. 0° Yaw 1deg	3deg
20		0.32	0.82
25		0.27	1.13
30		0.28	1.91
36		0.49	2.53

Table A4. MxWJ Model 5662-1, drag and side force measurements, powering tests at angles of yaw

Drag & Side Forces at Angles of Yaw (POWERED)									
	Drag Force (lbs)			FWD Side Force (lb)			AFT Side Force (lb)		
VS (knots)	0deg Yaw	1deg Yaw	3deg Yaw	0deg Yaw	1deg Yaw	3deg Yaw	0deg Yaw	1deg Yaw	3deg Yaw
20	4.25	4.45	4.93	0.00	-2.31	-8.03	0.00	1.89	5.06
25	6.32	6.73	8.01	0.00	-3.82	-14.28	0.00	2.93	9.16
30	8.44	9.07	10.53	0.00	-7.33	-23.22	0.00	5.67	14.71
36	11.75	12.99	15.55	0.00	-15.28	-37.84	0.00	11.60	24.30

	Drag Force (lbs)		
VS (knots)		Δ vs. 0° Yaw 1deg	3deg
20		0.20	0.68
25		0.40	1.68
30		0.63	2.09
36		1.24	3.79

Table A5. MxWJ Model 5662-1, rotor force measurements, powering tests at angles of yaw

		Port Outboard						Starboard Outboard					
		0deg Yaw		1deg Yaw		3deg Yaw		0deg Yaw		1deg Yaw		3deg Yaw	
VS (knots)	Rotor RPM	Q (in-lbf)	T (lbs)	Q (in-lbf)	T (lbs)	Q (in-lbf)	T (lbs)	Q (in-lbf)	T (lbs)	Q (in-lbf)	T (lbs)	Q (in-lbf)	T (lbs)
20	1270.5	1.84	3.86	1.82	3.80	2.00	3.65	2.01	3.44	1.99	3.51	1.99	3.39
25	1534.4	2.92	5.50	2.88	5.42	3.03	5.15	3.10	4.95	3.09	5.01	3.12	4.97
30	1772.2	3.94	7.17	3.86	6.97	4.06	6.72	4.19	6.51	4.19	6.61	4.14	6.44
36	2096.1	5.68	9.91	5.52	9.46	5.75	9.29	5.96	9.04	5.97	9.13	5.94	8.89

		Port Outboard						Starboard Outboard					
				1deg Yaw Δ vs. 0° Yaw		3deg Yaw Δ vs. 0° Yaw				1deg Yaw Δ vs. 0° Yaw		3deg Yaw Δ vs. 0° Yaw	
VS (knots)	Rotor RPM			Q (in-lbf)	T (lbs)	Q (in-lbf)	T (lbs)			Q (in-lbf)	T (lbs)	Q (in-lbf)	T (lbs)
20	1270.5			-0.02	-0.06	0.16	-0.21			-0.02	0.07	-0.01	-0.05
25	1534.4			-0.04	-0.08	0.12	-0.35			-0.01	0.06	0.02	0.02
30	1772.2			-0.08	-0.20	0.12	-0.45			0.00	0.10	-0.05	-0.07
36	2096.1			-0.16	-0.45	0.07	-0.62			0.01	0.08	-0.02	-0.15

		Port Inboard						Starboard Inboard					
		0deg Yaw		1deg Yaw		3deg Yaw		0deg Yaw		1deg Yaw		3deg Yaw	
VS (knots)	Rotor RPM	Q (in-lbf)	T (lbs)	Q (in-lbf)	T (lbs)	Q (in-lbf)	T (lbs)	Q (in-lbf)	T (lbs)	Q (in-lbf)	T (lbs)	Q (in-lbf)	T (lbs)
20	1270.5	1.95	3.54	1.91	3.56	1.56	3.41	2.17	3.68	2.15	3.67	2.17	3.78
25	1534.4	2.97	5.03	2.97	5.05	2.60	4.82	3.16	5.26	3.14	5.23	3.17	5.30
30	1772.2	4.02	6.57	4.05	6.62	3.69	6.38	4.28	6.84	4.27	6.83	4.30	6.95
36	2096.1	5.73	9.03	5.74	9.11	5.42	8.87	6.05	9.34	6.02	9.38	6.05	9.55

		Port Inboard						Starboard Inboard					
				1deg Yaw Δ vs. 0° Yaw		3deg Yaw Δ vs. 0° Yaw				1deg Yaw Δ vs. 0° Yaw		3deg Yaw Δ vs. 0° Yaw	
VS (knots)	Rotor RPM			Q (in-lbf)	T (lbs)	Q (in-lbf)	T (lbs)			Q (in-lbf)	T (lbs)	Q (in-lbf)	T (lbs)
20	1270.5			-0.04	0.02	-0.38	-0.14			-0.01	-0.01	0.00	0.10
25	1534.4			0.00	0.02	-0.36	-0.21			-0.02	-0.03	0.01	0.04
30	1772.2			0.03	0.06	-0.32	-0.19			-0.02	-0.01	0.02	0.11
36	2096.1			0.00	0.08	-0.32	-0.16			-0.03	0.03	0.00	0.21

Table A5. MxWJ Model 5662-1, rotor force measurements, powering tests at angles of yaw - continued

VS	Rotor	Port Otbd Q			Stbd Otbd Q			Port Inbd Q			Stbd Inbd Q		
knots	RPM	0deg	1deg	3deg	0deg	1deg	3deg	0deg	1deg	3deg	0deg	1deg	3deg
20	1270.5	1.84	1.82	2.00	2.01	1.99	1.99	1.95	1.91	1.56	2.17	2.15	2.17
25	1534.4	2.92	2.88	3.03	3.10	3.09	3.12	2.97	2.97	2.60	3.16	3.14	3.17
30	1772.2	3.94	3.86	4.06	4.19	4.19	4.14	4.02	4.05	3.69	4.28	4.27	4.30
36	2096.1	5.68	5.52	5.75	5.96	5.97	5.94	5.73	5.74	5.42	6.05	6.02	6.05

		Port Otbd Q		Stbd Otbd Q		Port Inbd Q		Stbd Inbd Q	
VS	Rotor	Δ vs. 0° Yaw		Δ vs. 0° Yaw		Δ vs. 0° Yaw		Δ vs. 0° Yaw	
knots	RPM	1deg	3deg	1deg	3deg	1deg	3deg	1deg	3deg
20	1270.5	-0.02	0.16	-0.02	-0.01	-0.04	-0.38	-0.01	0.00
25	1534.4	-0.04	0.12	-0.01	0.02	0.00	-0.36	-0.02	0.01
30	1772.2	-0.08	0.12	0.00	-0.05	0.03	-0.32	-0.02	0.02
36	2096.1	-0.16	0.07	0.01	-0.02	0.00	-0.32	-0.03	0.00

VS	Rotor	Port Otbd T			Stbd Otbd T			Port Inbd T			Stbd Inbd T		
knots	RPM	0deg	1deg	3deg	0deg	1deg	3deg	0deg	1deg	3deg	0deg	1deg	3deg
20	1270.5	3.86	3.80	3.65	3.44	3.51	3.39	3.54	3.56	3.41	3.68	3.67	3.78
25	1534.4	5.50	5.42	5.15	4.95	5.01	4.97	5.03	5.05	4.82	5.26	5.23	5.30
30	1772.2	7.17	6.97	6.72	6.51	6.61	6.44	6.57	6.62	6.38	6.84	6.83	6.95
36	2096.1	9.91	9.46	9.29	9.04	9.13	8.89	9.03	9.11	8.87	9.34	9.38	9.55

		Port Otbd T		Stbd Otbd T		Port Inbd T		Stbd Inbd T	
VS	Rotor	Δ vs. 0° Yaw		Δ vs. 0° Yaw		Δ vs. 0° Yaw		Δ vs. 0° Yaw	
knots	RPM	1deg	3deg	1deg	3deg	1deg	3deg	1deg	3deg
20	1270.5	-0.06	-0.21	0.07	-0.05	0.02	-0.14	-0.01	0.10
25	1534.4	-0.08	-0.35	0.06	0.02	0.02	-0.21	-0.03	0.04
30	1772.2	-0.20	-0.45	0.10	-0.07	0.06	-0.19	-0.01	0.11
36	2096.1	-0.45	-0.62	0.08	-0.15	0.08	-0.16	0.03	0.21

(Data regrouped for alternative comparisons)

Table A6. MxWJ Model 5662-1, waterjet nozzle priming level as a function of pump inlet submergence, with variations in rotor RPM and model speed

Test		Submergence @ Pump Inlet		Model Quantities Set		Nozzle Filled	Notes	Ship Quantities	
		(inch)	(Ratio)	(kts)	RPM	(%)		(kts)	RPM
76	Condition 1	1.99	0.57	0	100	10	water moving	0	17
	Baseline	1.99	0.57	0	200	50		0	34
	57% Subm	1.99	0.57	0	300	80		0	51
		1.99	0.57	0	400	90	pretty close to "primed" = full nozzle	0	68
		1.99	0.57	0	500	100	primed	0	86
		1.99	0.57	0	600			0	103
		1.99	0.57	0	700			0	120
		1.99	0.57	0.5	100	10	water moving	2.9	17
		1.99	0.57	0.5	200	50		2.9	34
		1.99	0.57	0.5	300	80	around 250rpm - half to almost full	2.9	51
		1.99	0.57	0.5	400	90	close to full, sloping down	2.9	68
		1.99	0.57	0.5	500	100	primed - same as 0 speed	2.9	86
		1.99	0.57	0.5	600			2.9	103
		1.99	0.57	0.5	700			2.9	120
		1.99	0.57	1.0	100	10	water moving	5.8	17
		1.99	0.57	1.0	200	60	little more than 1/2 full	5.8	34
		1.99	0.57	1.0	300	90	close to full	5.8	51
		1.99	0.57	1.0	400	95	full, sloping down	5.8	68
		1.99	0.57	1.0	500	100	primed	5.8	86
		1.99	0.57	1.0	600			5.8	103
		1.99	0.57	1.0	700			5.8	120
77	Condition 2	1.65	0.47	0	100	10	water flowing	0	17
	47% Subm	1.65	0.47	0	200	25	1/4 full	0	34
		1.65	0.47	0	300	50		0	51
		1.65	0.47	0	400	80	80% full, sloping down	0	68
		1.65	0.47	0	500	90	full but sloping down	0	86
		1.65	0.47	0	600	100	primed => +100rpm looks similar to DES	0	103
		1.65	0.47	0	700			0	120
		1.65	0.47	0.5	100	10	water moving	2.9	17
		1.65	0.47	0.5	200	25		2.9	34
		1.65	0.47	0.5	300	50		2.9	51
		1.65	0.47	0.5	400	80	semi full, downward slope	2.9	68
		1.65	0.47	0.5	500	90	primed, slope	2.9	86
		1.65	0.47	0.5	600	100	primed fully	2.9	103
		1.65	0.47	0.5	700			2.9	120
		1.65	0.47	1.0	100	10		5.8	17
		1.65	0.47	1.0	200	33		5.8	34
		1.65	0.47	1.0	300	75	big change in volume of vater ~1/3 to 3/4 full	5.8	51
		1.65	0.47	1.0	400	90	full but sloping down	5.8	68
		1.65	0.47	1.0	500	100	primed, maybe a little slope	5.8	86
		1.65	0.47	1.0	600			5.8	103
		1.65	0.47	1.0	700			5.8	120
78	Condition 3	1.29	0.36	0	100	10	moving water	0	17
	36% Subm	1.29	0.36	0	200	25		0	34
		1.29	0.36	0	300	50	maybe 50% full	0	51
		1.29	0.36	0	400	70	big jump towards full. Large slope	0	68
		1.29	0.36	0	500	80	not much change	0	86
		1.29	0.36	0	600	90	looks like 500rpm of previous cases	0	103
		1.29	0.36	0	700	95		0	120
		1.29	0.36	0	800	100	looks fully primed	0	137
		1.29	0.36	0.5	100	10	moving water	2.9	17
		1.29	0.36	0.5	200	25	1/4 full	2.9	34
		1.29	0.36	0.5	300	50		2.9	51
		1.29	0.36	0.5	400	80	80% full, big jump	2.9	68
		1.29	0.36	0.5	500	90	95% full	2.9	86
		1.29	0.36	0.5	600	95	full, sloping down	2.9	103
		1.29	0.36	0.5	700	100	looks like 800rpm at zero speed	2.9	120

Table A6. MxWJ Model 5662-1, waterjet nozzle priming level as a function of pump inlet submergence, with variations in rotor RPM and model speed - continued

Test		Submergence @ Pump Inlet		Model Quantities Set		Nozzle Filled	Notes	Ship Quantities	
		(inch)	(Ratio)	(kts)	RPM	(%)		(kts)	RPM
78	Condition 3	1.29	0.36	1.0	100	10		5.8	17
	36% Subm	1.29	0.36	1.0	200	25	25%	5.8	34
	(continued)	1.29	0.36	1.0	300	50		5.8	51
		1.29	0.36	1.0	400	80	90%	5.8	68
		1.29	0.36	1.0	500	90	looks close to full	5.8	86
		1.29	0.36	1.0	600	100	primed	5.8	103
		1.29	0.36	1.0	700			5.8	120
79	Condition 4	0.93	0.25	0	100	0	minimal moving water	0	17
	25% Subm	0.93	0.25	0	200	5		0	34
		0.93	0.25	0	300	10		0	51
		0.93	0.25	0	400	20	not much change 20% filled	0	68
		0.93	0.25	0	500	25	25% maybe	0	86
		0.93	0.25	0	600	30		0	103
		0.93	0.25	0	700	35	not much volume change	0	120
		0.93	0.25	0	800	40		0	137
		0.93	0.25	0	900	45		0	154
		0.93	0.25	0	1000	50	not yet 50%	0	171
		0.93	0.25	0	1200	60		0	205
		0.93	0.25	0	1400	65		0	240
		0.93	0.25	0	1600	70		0	274
		0.93	0.25	0	1800	75	maybe 75% full	0	308
		0.93	0.25	0.5	200	5	tiny bit flowing	2.9	34
		0.93	0.25	0.5	400	20		2.9	68
		0.93	0.25	0.5	600	40		2.9	103
		0.93	0.25	0.5	800	50	maybe 50%	2.9	137
		0.93	0.25	0.5	1000	60		2.9	171
		0.93	0.25	0.5	1200	65		2.9	205
		0.93	0.25	0.5	1400	70		2.9	240
		0.93	0.25	0.5	1600	75	about the same as zero speed top RPM	2.9	274
		0.93	0.25	0.5	1800	80	not primed	2.9	308
		0.93	0.25	1.0	200	10	flowing	5.8	34
		0.93	0.25	1.0	400	20		5.8	68
		0.93	0.25	1.0	600	40	about the same as 0.5 knots thru range	5.8	103
		0.93	0.25	1.0	800	50	maybe 50%	5.8	137
		0.93	0.25	1.0	1000	60	about the same as 0.5 knots thru range	5.8	171
		0.93	0.25	1.0	1200	70	"	5.8	205
		0.93	0.25	1.0	1400	75	"	5.8	240
		0.93	0.25	1.0	1600	80	"	5.8	274
		0.93	0.25	1.0	1800	90	Not Primed	5.8	308
		0.93	0.25	1.0	2000	95	getting close ~90%	5.8	342
		0.93	0.25	1.0	2200	100	PRIMED	5.8	377
							hyteresis loop, stayed primed all the way down to 400rpm		

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